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ABSTRACT

For the next ten years, at least, it would almost certainly be prohibitively expensive for a student to receive a major part of each day's instruction in a direct individual dialogue with a computer. Furthermore such a system would not teach a student to interact effectively with other humans, to communicate the results of his labors to others, or to exchange ideas in attempts to solve shared problems. For the present, the computer is most useful in its role of a general purpose information processing system. Individualized instruction allows the mode, content and sequence of instruction to be tailored to the individual's needs at any moment in time. A computer is an important tool in individualizing instruction. The computer can be used as a teaching machine, a problem solving tool, or as a tutorial system. The remainder of this paper is a survey of the state of the art in computer-based tutorial systems with special reference to the work being done at the System Development Corporation. A short list of references is provided. (JY)

# Computer-Assisted Instruction and Its Potential for Individualizing Instruction

John E. Coulson*

Picture a college student of 1975, arriving at his study center in the morning and immediately sitting in front of a sophisticated console complete with tape recorder and earphones, slide and motion picture projectors, a television screen, a keyboard, and an electronic pen allowing free-hand student responses. This console, along with thousands of others on the campus, is connected to and controlled by a large central computer. The student receives instruction by means of multi-media presentations, and uses a variety of response modes to answer questions about the content material. The computer evaluates all responses and provides immediate corrective feedback. When the student needs further information to help him solve a problem he communicates through the computer with a comprehensive automated library, typing his questions in normal English format and receiving immediate answers. He works entirely at his own pace and may see an entirely different sequence of material than any other student. With appropriate breaks for coffee and lunch, the student works in this individual manner until he is ready to go home in the afternoon.

The system just described is technologically feasible today. But does it represent a likely picture of college life in 1975? I believe not, for at least two important reasons.

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The first reason is purely economic. For the next 10 years, at least, it would almost certainly be prohibitively expensive for every student to receive a major part of each day's instruction in a direct, individual dialogue with a computer. I will discuss some of the economic considerations of computer-aided instruction in a later section of this paper.

But a more important reason, I believe, is that an education based exclusively or predominantly on a closed-system, man-computer dialogue would be terribly sterile in several important respects, no matter how efficiently the students might acquire content skills. Such a system, in fact, would increase an already unfortunate tendency for education to divorce itself from such important skills as the ability to interact effectively with other humans, to communicate the results of one's labors to others, and to exchange ideas in attempts to solve shared problems.

The reservations that I have expressed thus far do not mean that I believe computers are useless in instruction. On the contrary, I hope to make it clear in this paper that computers will probably play a major role throughout college education within 10 to 20 years. But to understand the potential impact of computer technology on higher education, we need to stop thinking of the computer simply as another audio-visual aid, a desk calculator, or a glorified teaching machine, and begin to appreciate its capabilities as a general-purpose information-processing system. And when we speak of the role of computer-aided instruction in individualizing college instruction, we must clearly define what we mean by individualized instruction, and what techniques we subsume under the label, "computer-aided instruction."

INDIVIDUALIZED vs INDIVIDUAL INSTRUCTION

Toward this end, I should first like to make a distinction between "individualized instruction" and "individual instruction." Individual instruction implies that the student is moving entirely independently, with little or no interaction with his fellow students. Such instruction cannot, in itself, provide a total education although it may do an excellent job of teaching certain skills. Other, equally important skills require group interaction.

Individualized instruction, as distinguished from individual instruction, means that the mode, content, and sequence of instruction are tailored to the individual's needs at any moment in time; it does not necessarily mean that he studies by himself although he may in particular circumstances. Thus in a single lesson a student might spend part of his time in self-study (e.g., with a programmed textbook), part of his time watching a film in a large auditorium, and part in a group discussion, yet the entire lesson sequence might be highly individualized.

To insure that each student receives a sequence of instructional experiences that provides effective individualized instruction, a college or other educational institution must have, in addition to its staff, at least three major resources: A large pool of teaching materials designed to produce specified types of behavior; a monitoring and evaluation system to provide continuous assessment of individual performance; and a decision and control mechanism for matching the instruction to the individual needs. The typical college today lacks all three of these resources. There are many textbooks and teaching aids available to augment the instructor's lectures, but these are too often designed to cover a certain amount of content area rather than to produce specified student behaviors. Student assessment is usually piecemeal, haphazard, and infrequent, and consequently has little impact on the instruction. The instructor spends most of his time lecturing, or doing his own research, and has little opportunity to assign different students to different learning modes according to their assessed needs. Thus the lock-step system so common in the public schools often prevails in higher education as well. College students may select their courses cafeteria-style, but once they are in a course they will probably all get the "blue-plate special."

Some small colleges and universities, such as Bucknell, are fortunate to have small student/teacher ratios, and can individualize instruction to a considerably greater extent than the large schools. Even here, however, there is a definite limit to the capacity of any manual bookkeeping system for tracking students who are moving independently, and for seeing that each student is in the right location at the right time, with the right teaching materials, and working in the optimal learning mode. Our research at SDC suggests that, ideally, it should be possible to individually assess and reassign each student to a different learning mode as many as 20 or 30 times a day. In the great majority of colleges and universities, at least, the sheer immensity of the bookkeeping required for such individualized instruction would make it essential that some form of automatic data-processing assistance be provided.

A modern computer has characteristics that closely parallel those needed in any educational system that wishes to provide highly individualized instruction. First, it has a very large memory capacity that can be used to store instructional content material or, under certain conditions, to generate such material. When the material is stored externally, as in reference books, films, etc., the computer can maintain records of the location and nature of the material for subsequent referral. The computer can also store extensive information about classrooms, faculty, teaching aids of all descriptions, and other school resources, as well as data on all students in the college.

Second, the computer can perform complex analyses of student responses inserted by keyboard, punched cards, electronic pen, or other techniques into the computer. It can operate so rapidly in this activity that large numbers of students can be individually assessed many times each day.

Finally, the computer can make decisions based on the assessments of student performance, matching resources to individual student needs. One such decision might be for the computer to present lesson materials directly to the student in a tutorial mode. Other possible decisions might be to refer the student to a particular section of a textbook, to have him try a certain chemistry experiment in the lab, to seek consultation from an instructor, or to join a group discussion being conducted in a particular classroom. Whenever the student completed the assigned activity, he might be reassessed for assignment to a different activity. In the case of the chemistry experiment, for example, he might be required to insert the results of his experiment before he progresses further in his work.

COMPUTER-ASSISTED INSTRUCTION

Consideration of these computer capabilities brings us to a definition of the second key term in the title of this paper: "computer-assisted instruction." I view computer-assisted instruction as including anything a computer can do to help individualize and improve instruction. Thus the term encompasses not only the direct tutorial dialogue between computer and students, but also automated data-management aids to help instructors and administrators design curricula, monitor student performance, and manage classroom instruction.

In 1966, according to a report recently published by the American Council on Education, almost 600 American colleges, or approximately 30 percent of the total, had acquired at least one computer (Caffrey & Mosmann, 1967). The report estimates that, by 1970, more than half of all colleges and universities will have one or more computers. However, only a very small percentage of these machines are used for any purpose directly connected with instruction. Probably 95 percent of the on-campus computer time is used for routine processing of administrative records, payroll and budget calculations, attendance records, and similar activities. These are all important functions that help a college justify the expense of computers and associated machinery, but they fall outside the area of this paper's concern.

Five general applications are found for the remaining campus computer time, the five percent or so devoted to instructional assistance. These include the computer's use as: (1) a problem-solving tool for students; (2) a tutorial teaching device; (3) an automated library or information-retrieval system; (4) a classroom information system for instructors; and (5) a data-management aid for staff and administration in instructional planning. Each of these applications is discussed below, with examples based on actual or proposed projects.

The Computer as a Problem-Solving Tool

Among the computer applications fitting more directly under the heading of computer-assisted instruction, probably the most common, and certainly one of the earliest, is the computer's use as a problem-solving tool for the students. A primary example is the engineering student's use of a computer to solve mathematical problems in designing, let us say, a concrete wall that must withstand certain specified stresses. In such an application the computer serves much the same function as a slide rule or a desk calculator. The computer has one significant advantage as a pedagogical tool, however, aside from its greater power and speed. Before the student can make the computer solve his mathematical problem, he must analyze the problem and explicitly formulate its solution as a series of discrete, operationally defined steps corresponding to the computer's repertoire of operations. In performing the requisite analysis and logically ordering the computer's operations, the student often gains a much better understanding of the original problem, and is better prepared to solve subsequent problems of a similar nature.

A special instance of the computer's application as a problem-solving tool is its use to teach students about computers and computer programming. Here the computer becomes the subject of, as well as the instrument for, instruction. Again citing the report of the American Council on Education, doctorates in computer science are offered at 15 universities in the United States and masters degrees at more than 30. In a far larger number of institutions, separate courses on computer design and programming are offered within the programs of the departments of mathematics, engineering, and other related disciplines. In these courses, an attempt is usually made to have students learn about the computer by using the computer, for example, by programming it to perform certain tasks. Frequently computers used for this purpose operate under an executive program containing a variety of diagnostic routines. When a student attempts to insert his own program he receives feedback messages telling him what kinds of errors his program contains.

The Computer as a Teaching Machine

More recently, computers have been used as sophisticated teaching machines. This is the application most popularly identified with the term, "computer-assisted instruction." In this mode a computer interacts tutorially with a student so that he moves through the course material at a rate and in a sequence determined by his responses to questions contained in the material. Some of the larger computer-based systems operate under a time-sharing program, which means that the same computer can give individualized instruction to many different students concurrently. In actuality the computer processes the students in turn, rather than simultaneously, but because of its great operating speed the computer can cycle through all the students so rapidly that no individual experiences any significant delay between inserting a response and receiving feedback from the machine.

The present paper is not primarily concerned with the history of computer-based tutorial instruction, but for those readers who wish to trace some of the earliest developments in this field, descriptions of practically all the original computer-aided instruction projects can be found in the proceedings of a 1961 "Conference on Programmed Learning and Computer-Based Instruction," jointly sponsored by the Office of Naval Research and System Development Corporation (Coulson, 1962). These early projects included work at International Business Machines, the University of Illinois, System Development Corporation, and Bolt Beranek and Newman. Listings and brief abstracts of more current computer-assisted instruction projects are being maintained by Karl L. Zinn at the University of Michigan, and by ENTELEK Incorporated, Newburyport, Massachusetts.

It is difficult to get any precise figures on the number of projects in this country presently using computers as tutorial teaching devices. In such a rapidly developing field new projects are started almost every month, and occasionally a project silently disappears. A reasonable total figure might be 30 or 35, with perhaps 20 of these located in various colleges and universities. Some of the projects are sponsored by computer manufacturers hoping to develop new educational markets for their products. The majority of projects are conducted as learning research laboratories or as experimental prototypes by universities and independent research institutions. There are probably fewer than half a dozen projects in which computer-based tutorial instruction is used as a routine part c a regular instructional program.

Computer-based tutorial systems come in a wide variety of sizes and shapes, but practically all have at least six major components: the computer; one or more terminals through which the computer and the students interact with each other; communication lines between computer and terminals; sequences of computer commands, called "programs," that control the actions of the computer;

the instructional content; and the students themselves. Each of these components is discussed below, with illustrative examples given from actual computer-based tutorial systems.

The Computer. The computer evaluates all student responses, assesses each student's immediate learning needs, and controls the presentation of lesson-material to the students. With perhaps one or two exceptions, all computers presently used for computer-assisted instruction are general-purpose machines originally designed for scientific or business applications. Like most general-purpose devices, they are quite versatile but are not ideally designed for any single type of operation. In the future, as the educational market grows, we may begin to see computers built specifically for educational purposes. Such computers might place less emphasis than most present-day machines on prodigious speed and calculation capabilities, and more emphasis on memory capacity, economy, and simplicity of operation.

Current computer-assisted teaching projects use computers of several different makes, including IBM, GE, RCA, Philco-Ford, and Control Data Corporation. IBM machines are in most common use, probably because of the greater number of these machines already on campus. The machines range greatly in size, speed, and cost. As a rough estimate of the price range, some of the smallest computers used for instruction cost around $80,000, while the larger machines run from two to three million dollars. Generally speaking, the larger computers, operating under a time-sharing system, can handle more students at the same time (theoretically a thousand or more for some of the largest machines although most systems currently handle only 20 to 50 students). They can also give more immediate feedback to the students, store more complete performance records on each student, perform a more complex analysis of responses, and provide more alternative lesson sequences to students who demonstrate varying levels of mastery. It must be kept in mind, however, that clever programmers can make even a small computer behave impressively, and poor programmers can waste most of a large machine's capability.

Terminals. A computer cannot effectively interact directly with the outside world. It is useless without input/output terminals to receive and transmit information. Most commonly, of course, the computer's outside world is represented by the humans using the machine.

As with the computers themselves, terminals are produced by numerous manufacturers and in a large variety of forms. Because of the highly interactive nature of computer-based tutorial instruction, a two-way communication device such as a teletypewriter is commonly used rather than a printing machine or other one-way device. Under computer control the teletypewriter can type instructions, diagnostic questions, and feedback messages to the student. The student, in turn, can use the teletypewriter keyboard to insert his responses to the computer's questions. Two other advantages of the teletypewriter are that it is less expensive than most other types of terminals, and it is more easily connected at sites remote from the computer. SDC's computer in Santa Monica, for example, is connected to teletypewriters in Massachusetts, New Jersey, Washington, and Ohio.

Despite the economy and convenience of the teletypewriter, it is a very noisy and slow device. Furthermore, there are some instructional situations that require more display capability, as in the presentation of graphic or pictorial material. With suitable engineering and programming, any type of presentation device can be controlled by a computer. One of the earliest systems developed by SDC used a random-access slide projector that could display up to 600 slides in any sequence directed by the computer (Coulson, 1962). The PLATO system developed by the Coordinated Science Laboratory at the University of Illinois displays material through closed-circuit television (Braunfeld, 1964). Two separate video pictures are superimposed on the student's TV screen. The televised problem frame contains spaces for the student's answers. When the student inserts his responses through a keyset, they automatically appear in the answer spaces.

In some learning situations it is very important that the student learn the relationships between symbolic and graphic information, as in the representation of mathematical functions. Licklider and Clark (1962) reported on an experimental computer-based instructional system in which the student could vary the coefficients of an equation and observe corresponding changes in the graph displayed on an oscilloscope screen. Alternatively, the student could sketch a graph on the screen, using an electric stylus, and then see the best-fitting function, along with its equation.

Auditory material must often be presented in teaching foreign languages, or in giving directions to young children. Several systems have been developed to provide random access to recorded messages, so that a computer can select them in any sequence judged to meet the learning needs of a student. IBM's 1500 Instructional System, for example, includes a computer-controlled tape recorder in addition to a slide projector and a cathode ray tube display. A similar random-access audio unit built by Westinghouse is used in an experimental teaching system at the University of Pittsburgh (Ragsdale, 1966).

Considerable variety is also seen in the devices used by students to indicate their responses to questions in the computer-controlled lesson sequences. Such devices must allow rapid student-computer interactions, and in most instances this rules out the more conventional computer input channels such as magnetic tapes and punched cards. The most common input device for computer-assisted instruction is the teletypewriter keyboard or other variety of keyset permitting constructed verbal responses. With such a device the student may give multiple-choice answers or short fill-in responses, or even write essays.

When graphic displays are provided on cathode ray tubes, it is often useful to allow students to specify certain areas on this display. For example, a geography student might be shown an outline of a hypothetical continent, and asked to locate the best sites for founding an industrial community. This can be accomplished through a light pen, which the student points at the cathode ray tube display to specify a point or area to the computer.

Another type of graphic input device, called the RAND Tablet, consists of a grid of extremely thin copper wires providing a surface that can be written on with an electric stylus. Using such a device the student can specify areas, draw lines, or even print letters and numbers that can be recognized by an appropriate programmed computer. We are currently experimenting at SDC with a RAND Tablet on which we are projecting images from a cathode ray tube. In this way we can superimpose stimulus and response material on the same surface.

At the University of Pittsburgh, a "touch-sensitive display" allows the computer to detect where a student touches the projection screen with his finger or a pointer (Ragsdale, 1966). Another device under development at Pittsburgh, the "manipulation board," detects the placement of objects, such as blocks, that the student might be asked to arrange in some pattern. The manipulation board and the touch-sensitive display are particularly useful for instruction of young children or mentally retarded students who might have difficulty operating a keyboard.

Communication Lines. Normally the communication lines might be subsumed under the discussion of the terminals themselves. I have broken them out as a separate item, however, because there are some very critical problems in linking computer and terminals that are almost always overlooked in general discussions of computer-assisted instruction.

The simplest type of terminal in common use today, the teletypewriter, can be linked to the computer by a standard telephone line. The installation charge for the teletypewriter is not very high, and the monthly rental is not prohibitive for most users, but the line charges themselves can be extremely costly if the terminals are located many miles from the computer. An hour of line use for computer-assisted instruction will cost the same as a conventional telephone conversation of the same duration and distance. Even at short distances, this could add up pretty fast if hundreds of terminals were being used several hours every day. Thus the communication costs must be a major consideration in any plans for a centralized system in which a single computer is intended to service many schools or campuses over a broad geographic area.

The communication costs are increased many times when terminals are used that require a high density of data transmission. This is true, for example, of many graphic display devices which must be connected to the computer by special high-speed data lines or microwave circuits. Aside from the costs, the use of such terminals also makes the problem of transmission reliability more acute.

Programs. In most computer-based tutorial applications two types of computer programs are required. One type of program is specific to a particular lesson; it contains all the directions to the computer for sequencing the lesson material, evaluating responses, and giving feedback in that lesson. The other type is the control program under which the lesson program is executed. It contains general commands, for example, about how control is to be passed from the student to the computer, and back again.

A lesson program contains the pedagogic strategies for the lesson. Our own experience indicates that the strategy cannot be standardized or stereotyped; it must be tailored to the subject matter covered by the particular lesson and may, in fact, change several times during the lesson. In other words, you cannot establish a rigid pattern and say, for example, that every new topic must be introduced by an instructional frame defining the new concept, followed by three examples illustrating and elaborating on the definition, followed by two question-frames requiring the student to demonstrate mastery of the concept. Such an arbitrary rubric may lend an aura of scientific rigor, but it will inevitably fail the test of practical utility. In the present state of the art, there is no substitute for empirically determining what lesson sequence will be most effective for each topic.

Commonly, an attempt is made to accommodate individual differences among students by means of a branching structure with alternative sequences of lesson material for each topic. On a given topic, one sequence may provide only the bare essential facts; a lower level sequence on that same topic may provide more redundancy and more concrete examples; and a third sequence may give still more practice and repetition, and may phrase the information in shorter, less gramatically complex sentences. Thus a bright student performing well on the material might move rapidly from one topic to the next, seeing relatively few instructional frames and always being kept at the more concise level of exposition, while a slower student might be dropped to successively lower, and more redundant levels in the program until he shows mastery of each topic. Our work with such sequences at SDC indicates that mere repetition or rephrasing of a concept in simpler terms is not adequate. If a student does not learn from one sequence, he should be given a new sequence that takes an entirely different approach to the topic. For example, if the original sequence takes a deductive approach, presenting a rule or principle and then giving examples, the remedial sequence might take an inductive approach, in which the student induces the principle from a series of concrete examples and applications.

A number of different response characteristics can be taken into account in the computer's branching decisions. For example, the decision may be based on a detailed analysis of a single response, where the nature of the student's error suggests a particular misunderstanding that may be eliminated by a particular remedial sequence. Or, branching may be based on error counts accumulated over a number of instructional frames. If a student makes fewer than two errors out of eight questions on a topic, for instance, this might cause the program to branch ahead to a new topic; two to four errors might cause it to present a brief remedial sequence; and more than four errors might lead to the student's being started over on the topic, with less complex material.

Other response measures sometimes used in the branching decisions include response latency, and the student's own expression of confidence in his understanding of a topic. Both of these measures, however, are of somewhat uncertain value, being difficult to calibrate because of the great degree of variability from one student to another, and even within the individual student from one content area to another.

The control program, which may actually consist of several interrelated programs, controls the insertion of lesson-specific programs into the computer. It also governs the overall execution of the lesson programs when the lessons are presented to students. In some computer-based teaching systems the lesson author first prepares his lesson information in flow charts showing the lesson sequence and branching instructions. This information is later transcribed onto coding sheets, then punched onto cards, and finally read into the computer. Such a system can be cumbersome. The lesson author has little direct control over the actual insertion of his material, and he must wait at least several hours, and usually a day or more, before he sees his lesson as compiled and executed by the computer. The delay and partial loss of control frequently encourage the author to prepare long lesson sequences before he attempts to get them into the computer. Because he then has a sizeable investment of effort in the long sequence, he may be reluctant to make any basic changes in it even if he detects flaws when it is "played back" to him by the computer, or even if the students' performance later reveals gross inadequacies in the material.

An alternative approach is to build into the control program the capability for the lesson author to insert his instructional sequence directly into the computer, through a teletypewriter or similar device. This "on-line" capability is provided by IBM's COURSEWRITER (Grubb, 1967) and SDC's PLANIT (Feingold, 1967).

In the "lesson construct" mode, PLANIT allows an author to specify the lesson content, the feedback messages, and the branching decision structure. In the "execute" mode, he can see any part or all of the lesson "played back" to him just as it would be presented to a student. In the "edit" mode, the author can insert new instructional frames at any point in the sequence, or delete or modify existing frames. He can switch immediately from any mode to any other to facilitate trials and revisions of small segments of a lesson.

PLANIT is designed to meet two requirements. The first is to give the lesson author a great deal of flexibility in the types of material he can prepare, and to minimize constraints on the types of responses that can be made by the student. The second requirement is to make the computer-assisted tutorial system user oriented. That is, both author and student should be able to communicate with the system without being computer specialists or spending a long time learning a new code.

To meet the need for flexibility, PIANIT provides many different options to the lesson author in the types of frames he can construct, and in the rules he can insert for sequencing those frames. For example, multiple-choice frames, constructed-response frames, and mathematical problem frames can be assembled in any sequence; there are no standard patterns to be followed. Either author or student can make use of a wide variety of mathematical and statistical subroutines. An author preparing a sequence of mathematical problems need not evaluate the problems for numerical solutions himself, but can merely specify the formulas which the computer can apply to check a student's response.

PIANIT also permits flexibility in the form of the student's responses. When the PHONETIC option in PIANIT is used by the lesson author, for example, a student's constructed response will be accepted as correct despite misspellings if it is phonetically equivalent to any answer previously designated as correct by the lesson author. Thus under the PHONETIC mode, "teechur" would be an acceptable approximation of "teacher."

Similarly, the KEYWORD option causes PIANIT to search for a designated set of words in the student's response. Under the KEYWORD mode, the lesson author might specify "John Kennedy" as the correct answer to a question and PIANIT would accept as correct the response, "I believe it was John F. Kennedy."

Finally, the FORMULA option gives the student credit for his answer if it is one of a subset of expressions algebraically equivalent to any of the designated "correct" responses. For example, the expression, $6(\frac{N}{4})$ would be accepted in place of the expression, $\frac{6N}{24}$.

The PHONETIC, KEYWORD and FORMULA options can be used in any combination selected by the lesson author, with different options for different items in the lesson sequence, if desired.

All of the options available to the lesson author increase his degrees of freedom, but also tend to complicate his task of constructing lesson sequences. To minimize possible confusion, and to make PLANIT a practical tool for the nonprogrammer, we have built the "lesson construct" mode, as well as the "execute" mode, in the form of a two-way dialogue between human and computer. The computer, through a teletypewriter, prints brief messages at each point in the lesson-construction process where the lesson author must provide information. These messages tell the author what type of information is needed before the computer can proceed with the lesson compilation. In the construction of a fill-in type question frame, for example, the computer asks the lesson author to specify the text of the question. After the author has typed the question, the computer asks him to specify all possible answers, correct or incorrect, that he wants the computer to treat in some special way. After the lesson author lists the answers, the computer asks him to specify the actions to be taken for each anticipated response. Depending on the student's response, the author may instruct the computer to tell the student to try again, to give the student a feedback message confirming his response or correcting his error, or to skip him backwards or forwards to some other segment of the lesson sequence. The author can also specify actions to be taken if the student gives an unanticipated wrong answer.

<u>Content Material.</u> There seems to be a popular misconception that, if you use a large computer and an elaborate branching structure with many alternative

lesson sequences, you can be somewhat casual about the preparation of the content material itself. Nothing could be further from the truth. If anything, more time and effort must go into the development of lesson materials for a computer-based teaching system than for a programmed textbook or a simple teaching machine. Although practically anyone can write lesson sequences at a high rate, the development of effective material is many times slower. At one point in our research at SDC, we estimated that it took two man-years to develop 20-hours worth of material. One reason for this slow rate is that in computer-assisted instruction, not only the main sequence, but all the auxiliary branching sequences and remedial loops as well must be carefully tested and revised to ensure that each sequence does the job for which it was designed. This means, first, determining that there is a sufficiently sensitive diagnostic measure of the student's strengths and weaknesses at each point in the lesson sequence, and second, making certain that each remedial loop remedies whatever learning deficiency has been detected. Otherwise, as we have unfortunately found in some of our own research, a student may be directed through two or three remedial sequences and still perform poorly on a posttraining criterion test.

Careful preparation of lesson material does not necessarily require exposing the material to large numbers of students. It does mean working intensively with small lesson segments and individual students, testing and revising each segment until it achieves its objectives. We have found that more can be learned by working very closely with 15 or 20 students, one at a time, observing the details of their behavior, than by simply studying statistical summaries of the responses of several hundred students.

Students. The students we have worked with and those we have heard about, regardless of grade level, have not been awed, frightened or intimidated by their experiences with computer-assisted instruction. However cleverly we may program the computer, every student soon sees it for what it is: another learning tool, like a textbook or slide rule. And like other learning tools, the computer and its various appendages are viewed as things to be manipulated to the students' own advantage. Some forms of manipulation are less adaptive than others, as when one of our younger students unscrewed the bulbs from several display boxes, but in general we try to encourage the student's feeling that the computer and the input/output terminal are there to help in some learning task, not to make life difficult for him.

Initially, almost all students exhibit a "pinball machine" effect, that is, a motivational lift resulting from the novelty and the automation of the equipment. This effect cannot be expected to have permanence, however; the content material must have intrinsic interest beyond the mechanical gadgetry. One of the most difficult tasks in the development of lesson material is to present information efficiently and economically, yet maintain student interest and curiosity. In some instances motivation appears to be enhanced by the insertion of peripheral comments having no direct relevance to the learning objectives of the particular lesson.

Automated Library and Information-Retrieval Systems

For a number of years computers have seen increasing use, especially in some of the larger universities, for automated handling of certain library functions such as indexing and classification, abstracting, and cataloging. These are basically bookkeeping chores, and though such computer applications save time and reduce clerical effort, they do not solve the basic problem of bringing students in closer contact with the information they should have. Typically, students today must walk to a separate building to obtain library materials, and then they must fill out forms and wait some appreciable time before they receive the material. If they find that the initial materials do not answer their questions, they must wait again before they can see a new set of materials. This obstacle between students and library information has an inhibitory effect on the entire process of student inquiry. It means that, in the more crowded colleges, at least, most students do not seek new information on their own initiative; they search only as far as they must to meet specific requirements levied by the instructor. Or, if the students do any voluntary study in the library, they tend to perceive this activity as quite separate and distinct from the classroom instruction.

What appears to be needed is a method of reducing the obstacles between students and information, and of bringing classroom learning and inquiry together as one integrated process. An important step in this direction is to eliminate the information middle-man, and to give students direct access to a wide variety of reference material. This, I would assume, should be one goal of the dial access information system at Bucknell University.

To take full advantage of improved information-retrieval systems such as the dial access system, changes are needed in the classroom instruction so that inquiry and retrieval activities are an integral part of the instruction. The instruction may present factual problems requiring the students to retrieve specific pieces of information, or it might contain open-ended, discussion-type problems stimulating the students to browse more widely through reference materials so as to gain a broader perspective and more angles of approach on the problems.

The language used between student and computer is another important factor in the effectiveness of computer-based inquiry systems. SDC has been working for several years on a natural-language information-retrieval system that allows a student or other user to ask questions of a computer in his own words. The system uses a computer program, called SYNTHEX (Simmons, 1967), that performs a syntactic analysis of the questions and responds to them by typing out relevant statements from a library of statements in memory. Experiments with SYNTHEX, using the Golden Book Encyclopedia as a data base, have demonstrated the technological feasibility of this question-answering approach, but much more work is needed to make it a practical tool for education.

## The Computer as a Classroom Information System for Teachers

Where it is not practical or desirable to have a computer interact directly with students, it can be used as an information system to aid teachers in the individual monitoring and management of student progress. The Instructional Management System (IMS), developed by System Development Corporation, and currently being used experimentally in two California schools, provides such capabilities. Other systems, designed for similar purposes, include the Individually Prescribed Instruction (IPI) system developed by the University of Pittsburgh, and the Program for Learning in Accordance with Needs (PLAN), developed jointly by the American Institute for Research and Westinghouse Learning Corporation.

IMS is a technological tool--a combination of materials, equipment and procedures designed to give teachers both diagnostic and prescriptive information about individual children or groups of children in the classrooms. A computer maintains a pupil data base containing background information and current performance data for each pupil. It also stores information about available seatwork and other exercise materials relevant to each specific learning objective. As the pupils complete each instructional unit, they are given diagnostic tests on machine-readable answer sheets. These tests are not the conventional type of global assessment test; they are designed to give precise evaluations of performance on individual learning objectives defined in terms of the desired pupil behaviors. Te results are used to update the pupil performance records, and on the day after each test the teacher receives machine-prepared summaries showing the pupils' progress and indicating which pupils performed poorly on which tasks. The summary also suggests alternative instructional materials or teaching techniques that the teacher might use for pupils with specific weaknesses. Through a teletypewriter terminal, teachers and administrators can query the computer's data base for summarized or detailed information about individuals or groups of pupils.

IMS is designed to operate initially in the context of a conventional classroom organization, in which groups of pupils move at the same pace with little opportunity for individualized instruction. However, it is anticipated that, through its capability for presenting diagnostic and prescriptive information on an individual basis, IMS will help schools to move toward a more flexible continuous-progress mode of operation. IMS also appears to offer a better chance for economically practical application in public schools than direct computer-assisted instruction of students, at least for the next five or ten years.

Future plans for IMS include the enhancement of both its diagnostic and prescriptive capabilities. Although diagnosis is presently restricted to simple percentage scores on multiple-choice questions, it is quite possible to incorporate other, more complex types of evaluation. In the more advanced grades, for example, the computer might be used to grade essay material. Such a capability has already been developed at the University of Connecticut and applied experimentally to the grading of English essays (Page, 1966). Preliminary results suggest that computers are capable of relatively complex analyses in evaluating discursive responses, and may approach the level of evaluative sophistication of the typical high school teacher. More study will be needed to determine whether such computer applications are of practical utility in the schools.

On the prescriptive side, we plan to explore the possible uses of a computer to increase the quantity and variety of instructional material available to teachers to remedy learning deficiencies detected by IMS. One type of computer program that we hope to develop will describe the characteristics of lesson sequences that need to be written or adapted to fill gaps in the existing material. For example, based on an analysis of student response profiles, the computer might print a message saying, "More than 30 percent of the students show inadequate mastery of transposition rules in algebra. A new lesson segment is needed with the following sequence of instruction:

(1) drill work on arithmetic operations; (2) review of rules of transposition; and (3) drill work on application of transposition rules."

Another computer program that we will be working on over the next few years will actually assemble lesson sequences, drawing from a pool of instructional frames generated by human authors. To accomplish this we will have to give the computer not only the pool of frames, but a set of descriptor values for each frame, and a set of rules telling the computer how to draw samples of frames according to their descriptor values, and how to sequence the frames to meet specific learning needs revealed by the performance profiles.

Finally, under certain conditions it is possible to program the computer to construct its own frames as well as to sequence the frames. For example, it is extremely simple to have a computer generate any desired quantity of addition problems, using different combinations of numbers.

In coming years we hope to extend our application of IMS to other grade levels. Although our current work has been exclusively at the public school level, I believe that, with suitable adaptations, it could be an extremely useful tool for higher education as well.

## Administrative Data-Management Systems

Since the ultimate purpose of schools and universities is to teach, it seems reasonable that teaching effectiveness, as measured by student performance, should be an important factor in management decisions at the top administrative level of those institutions. Ironically, information about learning progress is rarely considered in the major policy decisions of the typical school or university. These decisions are based largely on economic or political considerations, or are forced by the sheer logistics of trying to keep a rapidly growing number of students busy and out of trouble. The rare exception, when the administrator becomes seriously concerned with student performance, is when they do poorly on some standardized test relative to other institutions, especially if the results are widely publicized.

We are attempting at SDC to develop procedures that will help administrators use student performance data in their administrative decisions. We feel that the use of such data should not be a chance occurrence, but a regular part of the administrative routine. Three things are needed before this goal can be accomplished: (1) The college or school district must have clear-cut, operational objectives with assigned priorities, and at least some of these objectives must be defined in terms of student performance; (2) administrators must have baseline data on student performance in different subject areas, so that they have some relative basis on which to set performance standards; and (3) they must have ready access to information about current performance. This information should not be in the form of large quantities of raw, unmanageable data, but in brief summaries tailored to the administrator's needs.

Some progress is being made toward meeting these three requirements. A number of colleges and universities have recently started efforts to define their objectives more operationally and to set some type of performance standards. This trend is further encouraged by the growth of programmed instruction and by the application of systems analysis techniques in education, as both of these methods place heavy emphasis on the definition of objectives and performance measures.

To aid in the need for better performance data, SDC is developing a computer-based data-management system designed to provide administrators with accurate, up-to-date student performance summaries, along with budget and personnel data. This system, called SPIAN (Krebs & Yett, 1966), allows administrators to query the computer's data base through a teletypewriter in the administrative office. The project is still in its early exploratory stages, but in one small school district where we are currently working with SPIAN, we have seen the superintendent and his staff begin to include student performance as an agenda item in their regular staff meetings. Perhaps it is not too far-fetched to envision the day when all colleges, universities, and districts will base their budget and personnel allocations at least partially on the students' performance in different subject areas, with greater resources being assigned to areas where performance is deficient.

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